

***Fuselage Hardening for Fire Suppression:  
Safety Benefit Analysis based on  
Past Accidents***

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## **Abstract**

*A study has been carried out to assess the potential benefits, in terms of reduction of fatalities resulting from improvements in cabin burnthrough resistance to ground pool fires.*

*The International Cabin Safety Research Technical Group's Survivable Accidents Database was used to identify past aircraft accidents and extract detailed data for those accidents where fuselage burnthrough was an issue in the survivability of the occupants. Seventeen accidents were identified and divided into scenarios where it was assessed that there was a similar level of threat to the occupants. A mathematical technique was used to model each accident scenario and Monte Carlo simulations were carried out to assess the likely range of the assessed benefit.*

*A range of burnthrough protection times was considered and results are presented for additional protection times from 30 seconds up to 8 minutes.*

*It is concluded that fire hardening of fuselages will provide positive benefits in terms of enhanced occupant survival and may be found to be cost beneficial if low cost solutions can be found. The maximum benefit, over the period covered by the data, was assessed to be a saving of 10.5 lives per year for aircraft configured to the current airworthiness requirements.*

# 1 Introduction

This paper describes the methodology and results of a benefit analysis carried out on fuselage hardening for burnthrough protection against large ground pool fires.

A number of past accidents have been identified which are considered to have involved fire penetration of the passenger cabin with a consequential threat to occupant survival. For each of the accidents identified, the assessed benefit in terms of the reduction in number of fatalities has been derived assuming improvements to the fire hardening properties of the aircraft fuselage. Benefits have been assessed in the context of all survivable accidents and results are presented in terms of lives saved per year, over the years that were studied.

## 2 Objectives

The objective of this study was to assess the potential benefits, in terms of reduction of fatalities resulting from improvements in cabin burnthrough resistance to pool fires by:

- Using the International Cabin Safety Research Technical Group's Survivable Accidents Database to identify and extract detailed data for those aircraft accidents where fuselage burnthrough was an issue in the survivability of the occupants.
- Analysing each accident in depth to assess the number of lives and injuries that would be saved by a fire hardened fuselage.
- Assessing the benefits in the context of all survivable aircraft accidents.

## 3 Method

### 3.1 Selection of Accidents

Survivable or potentially survivable accidents on scheduled or non-scheduled passenger carrying transport aircraft were selected for inclusion in the analysis based on the following definition of a burnthrough accident:

*"An aircraft accident where the fuselage skin was penetrated by an external fire while live occupants were on board."*

This definition would exclude instances where the fuselage was consumed by fire after the evacuation period was complete and those accidents where the fuselage burnt through from the inside.

For the purposes of this analysis, the definition of a survivable accident is:

*"An aircraft accident where there were one or more survivors or there was potential for survival."*

Only survivable accidents, in which there were fire fatalities, were selected for analysis. Accidents in which there were no fire related fatalities were not analysed since there could be no benefit to be gained from a fire hardened fuselage.

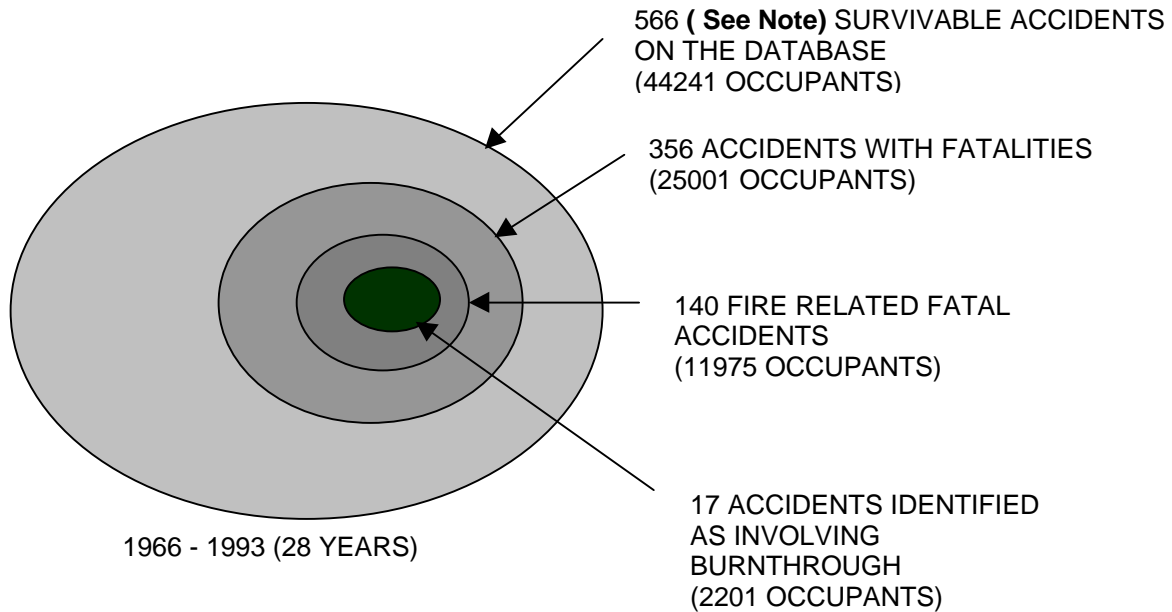
The accidents were selected using the Survivable Accidents Database of the International Cabin Safety Research Technical Group and from information contained in Reference 1.

Where accident information did not explicitly state that burnthrough had occurred, it was necessary to make the assumption that a pool fire existing outside an intact portion of fuselage would burnthrough, given the nature of the intensity of the fire.

Seventeen accidents were identified as listed in Table 1. The relationship between this subset and all fatal accidents on the database is shown in Figure 1.

Date	Location	Aircraft
14-Sep-1993	Warsaw	A320
01-Feb-1991	Los Angeles	B737
31-Aug-1988	Dallas	B727
26-Jun-1988	Habsheim	A320
22-Aug-1985	Manchester	B737
30-Aug-1984	Douala	B737
07-Dec-1983	Madrid	B727
13-Sep-1982	Malaga	DC10
07-Oct-1979	Athens	DC8
17-Dec-1978	Hyderabad	B737
15-Mar-1974	Teheran	Caravelle
30-Jan-1974	Pago Pago	B707
22-Jan-1973	Kano	B707
20-Dec-1972	Chicago	DC9
18-Apr-1972	Addis Ababa	SVC10
08-Apr-1968	Heathrow	B707
16-Feb-1967	Menado	L188

**Table 1: List of Burnthrough Accidents Identified**



**Note: This does not represent all Survivable Accidents over the time period considered**

**Figure 1: Relation of Selected Data to Whole Database**

### 3.2 Accident Scenarios

The severity of hazard in an accident can vary markedly throughout the aircraft. Experience has shown that considering occupant injuries on a “whole” aircraft basis can be misleading when assessing the effects of survivability factors. It is therefore necessary to divide the aircraft into “Scenarios”.

A Scenario is defined as:

*“That volume of the aircraft in which the occupants are subjected to a similar level of threat.”*

A similar level of threat need not necessarily result in the same level of injury to occupants. The extent of injury sustained can vary with numerous factors including age, gender, adoption of the brace position etc. Furthermore, the threat to occupants can vary over relatively small distances. For example, a passenger may receive fatal injuries because of being impacted by flying debris, and a person in an adjacent seat may survive uninjured. Dividing accidents into scenarios provides a more meaningful basis on which to analyse

accidents than considering the whole aircraft due to the marked variation in survival potential with occupant location.

The flight deck and flight attendant areas are generally considered as separate scenarios. The flight deck often has the potential for greater impact damage and crewmembers usually have full harness restraints. Furthermore, sliding cockpit windows in the area provide a nearby method of egress. The forward flight attendant areas are normally considered as a separate scenario from the passenger cabin due to the significant differences in seating, restraint systems and exit availability.

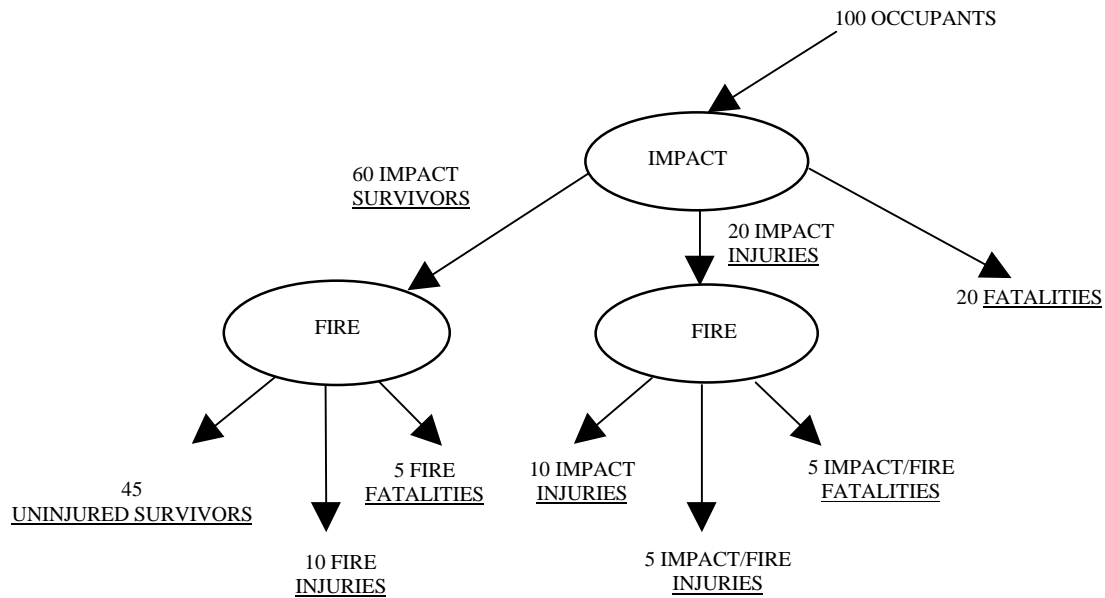
For these reasons, all analytical work carried out during this study has been based on carrying out assessments for each scenario.

### **3.3 Survivability Chains**

A mathematical model, known as a Survivability Chain has been developed such that the overall effect on survivability may be determined, from improvements made to survivability factors, taking into account injuries that may be sustained by occupants. A Survivability Chain was derived for each scenario in each accident.

For a scenario where injuries are sustained due to impact and subsequent fire, this has been modelled using two levels in the Survivability Chain.

An example of the model and the effects of improvement in injuries and fatalities resulting from changes to fuselage fire hardening are shown in Figure 2.

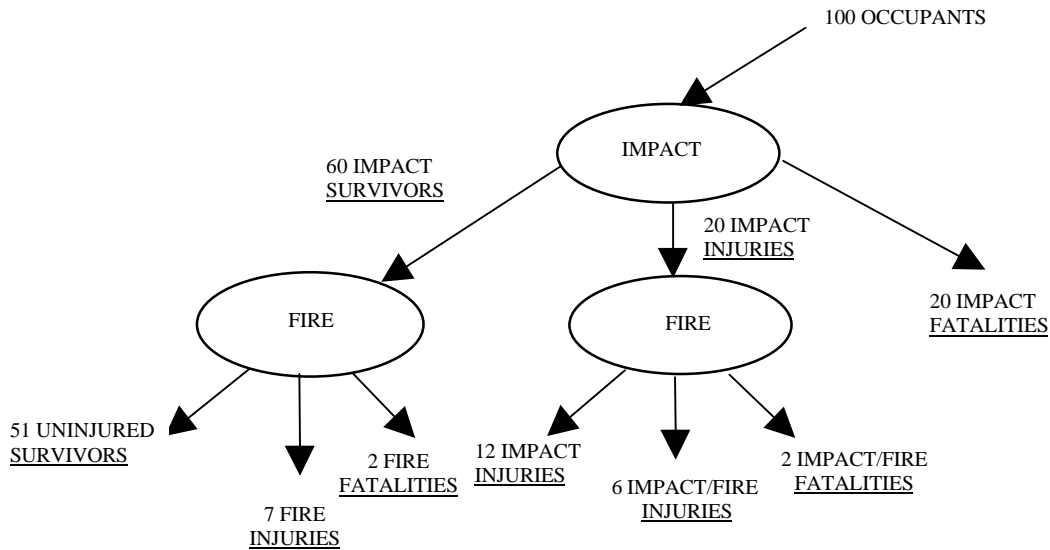


**Figure 2: Example Survivability Chain**

There are therefore:

- 45 uninjured survivors.
- 25 injuries, 10 as a result of the impact, 10 as a result of the fire, and 5 seriously injured as a result of the impact and fire.
- 30 fatalities, 20 as a result of the impact, and 10 as a result of the fire (5 of whom sustained non-fatal injuries from the impact).

If improvements were made to fuselage fire hardening, such that it was assessed there were now only 2 fatalities and 6 seriously injured, of the 20 impact injured occupants, and only 2 fatalities and 7 seriously injured, of the 60 impact survivors, then the survivability chain becomes as shown in Figure 3.



**Figure 3: Example of Survivability Chain Showing Possible Improvements in Survivability as a Result of Fuselage Fire Hardening**

Hence the improvement to the fuselage fire hardening results in:

- 51 uninjured survivors.
- 25 serious injuries, 12 as a result of the impact, 7 as a result of the fire, and 6 as a result of the impact and fire.
- 24 fatalities, 20 as a result of the impact, and 4 as a result of the fire (2 of whom sustained non-fatal injuries from the impact).

The overall situation is summarised as follows:

	<u>Survivors</u>	<u>Injuries</u>	<u>Fatalities</u>
Prior to improvement:-	45	25	30
Post improvement:-	51	25	24

Note that in this example, although the number of fatalities has been reduced, the number of injuries has remained constant. This is because an equivalent number of fatalities have been converted to injuries as injuries have been converted to uninjured survivors.



### **3.4 Statistical Modelling**

Software has been developed to use Survivability Chains in a mathematical representation of an accident using Monte Carlo Simulations. This simulation enables an assessment to be made of the change in numbers of survivors, injuries and fatalities resulting from predictions of the range of improvements that may be possible from enhancements to any particular survivability factor, in this case fuselage fire hardening.

For each scenario, assessments are made of the range of effects, in terms of the change in number of fatalities and injuries, resulting from improvements to fuselage fire hardening.

It is then assumed that there can be 100% confidence that the fatalities and injuries will lie in the range from the maximum to the minimum. The software makes random selections over the range 0% to 100% to arrive at a particular number of fatalities and injuries.

Random selections are made for all scenarios, in all accidents and the new total number of survivors may be calculated using all Survivability Chains. This is then compared with the actual number of survivors of the accidents to establish the number of lives saved. The iterations are then carried out many times to generate a distribution. From this distribution the 2½, 50 and 97½ percentile values are selected to represent a range of the likely improvement in lives saved for fire hardened fuselages.

It is recognised that the models are not perfect representations of an accident nor are the statistical assessments totally accurate. However, they will provide a better assessment of the likely impact of improvements to fuselage fire hardening than would otherwise be derived from a simple estimate of the resultant change in number of survivors.

### **3.5 Current Airworthiness Requirements**

Assessments of the improvements in the number of lives saved were carried out for the accidents based on the aircraft standard at the time of the accident. Each accident was then reanalysed taking into account the improvements that might have been made to numbers of lives saved if the aircraft had been configured to the current airworthiness requirements.

The requirements used to reassess the accidents were:

- Floor proximity lighting/markings
- Seat blocking layers
- Fire hardening of cabin interior materials
- Improved access to type III exits

### **3.6 Variation of benefit with burnthrough time**

The benefits of a fire hardened fuselage will depend on the achieved extension to burnthrough times. Since this study does not make any assumptions about how the enhanced burnthrough protection is achieved, it was necessary to employ a range of burnthrough times and repeat the analysis for a number of different values.

It was difficult to assess from the accident rationales exactly when burnthrough penetration occurred, therefore the assessments were based on incremental burnthrough improvement times.

The process of assessing the likely range of lives saved was repeated using the following increases in fuselage burnthrough times;

30 seconds,  
120 seconds,  
240 seconds and  
480 seconds.

The statistical model was run for each of the protection times and for both the actual aircraft configuration and the aircraft configured to the current requirements.

## **4 Results**

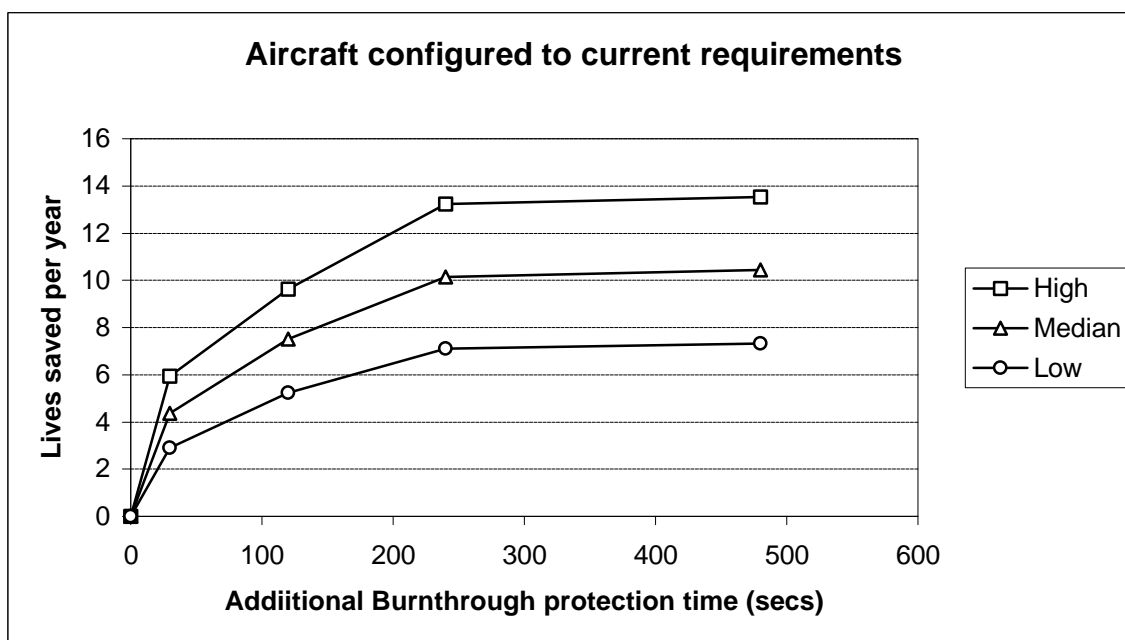
Seventeen accidents were identified as matching the selection criteria in 3.1 and were considered appropriate to use for the benefit analysis.

It was considered likely that there are other accidents where burnthrough was an issue but because there are little or no data available, they cannot currently be identified. If other burnthrough accidents have occurred then the derived benefit would increase. This is because the incremental change in lives saved is derived from the total number of occupants in all survivable accidents - which is a constant for the period considered. From a study carried out of the Survivable Accidents Database it is assessed that of the worldwide fire related fatal accidents (currently 140 on the Database) only 54% have sufficient data to assess whether burnthrough occurred. If the accidents not having available accident data have a similar benefit potential to those that do, then it is likely that the levels actually realised will be approximately 1.84 times ( $1/0.54$ ) those derived from the seventeen accidents studied.

The assessment of Benefit results are presented in Table 2 and Figure 4. They relate to aircraft configured to the current requirements standard and incorporate the factor of 1.84.

Additional Burnthrough Protection Time	Median Lives Saved	Median Lives Saved Per Year
30 seconds	122.4	4.4
2 minutes	210.1	7.6
4 minutes	284.5	10.1
8 minutes	292.7	10.5

**Table 2: Potential Life Saving for Aircraft Configured to Current Requirements**



**Figure 4: Variation of Improvement in Lives Saved Per Year with Additional Burnthrough Protection Time for Aircraft Configured to Current Requirements**

The fire penetration route was assessed for each of the seventeen accidents studied. The prime route was established to be via the fuselage skin and no evidence could be found to suggest that alternative routes, such as doors, windows or undercarriage bays, contribute significantly to occupant survival.

When comparing results from the aircraft in their actual configuration with aircraft configured to current requirements, it could be seen that benefits were slightly lower with aircraft configured to current requirements but exhibited the same characteristic in terms of increase with enhanced burnthrough protection time.

In two of the seventeen accidents studied, structural collapse occurred as a result of the fire. The exact time of structural collapse could only be established in one of these accidents and was found to be 18 minutes after the start of the fire. This study also suggests that there is limited increase in benefit beyond 4 to 8 minutes of additional burnthrough protection time. At this time, the evacuation process is complete and hence it is feasible that structural collapse is not a significant factor in accidents of this type. If this is confirmed then there would appear to be opportunities to find low cost solutions for enhanced burnthrough protection.

## 6 Comparison with previous studies

As part of a separate study (See Reference 2) a “representative set” of survivable accidents has been derived. This set of 55 accidents has been selected such that it has similar attributes to the entire population of survivable accidents involving fatalities (356). Within this set, there are four burnthrough accidents. It is assessed that these four accidents have the potential for 62 lives to be saved for an additional eight minutes of protection time for an aircraft configured to the current requirements.

Over the twenty eight year period involving a total of 356 survivable accidents this equates to:

$$(356/55) \times (62/28) = 14 \text{ lives per year}$$

Assessment of lives saved per year from this study	Assessment of lives saved per year based on the representative set of 55 accidents
10.5	14

**Table 3: Comparison with Representative Set**

The similarity of the two values suggests that the prediction of benefit, taking into account the accidents for which data is not available, is reasonably accurate.

## **7 Conclusions**

- 7.1 Fire hardening of fuselages will provide benefits in terms of enhanced occupant survival and may be found to be cost beneficial if low cost solutions are found.
- 7.2 The assessed highest reduction in fatalities from enhanced aircraft fire penetration resistance for aircraft configured to the current airworthiness requirements is 10.5 lives per year with 8 minutes of additional burnthrough protection.
- 7.3 The improvement in benefit increases with additional burnthrough protection time but shows limited increase in improvement beyond four to eight minutes.
- 7.4 The assessed benefit derived from this study is similar in magnitude to that determined from a study of a representative set of survivable accidents, thus providing some confidence in the results.
- 7.5 The prime fire penetration route is via the fuselage skin and no evidence could be found to suggest that alternate routes contribute significantly to occupant survival.
- 7.6 Aircraft configured to the current cabin safety requirements are likely to exhibit enhanced, but relatively limited, protection against external pool fires.
- 7.7 The reduction in the structural strength of the fuselage as a result of a pool fire appears to have a limited effect on occupant survival. If this is confirmed it is likely to result in a greater opportunity to find cost beneficial solutions to hardening aircraft against pool fires.

## **8 Acknowledgements**

The authors would like to thank the UK Civil Aviation Authority, Transport Canada and the US Federal Aviation Administration for their assistance in supplying accident reports and information on the accidents studied.

## **9 References**

- 1. CAA Paper 93010  
Cabin Water Sprays for Fire Suppression: Design Considerations and Safety Benefit Analysis Based on Past Accidents.
- 2. “Cabin Safety Research Prioritisation” R.G.W. Cherry & Associates Limited.